# Seasonal variation in biomass and species composition of seaweeds stranded along Port Okha, northwest coast of India

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Port Okha coast, which is known for its luxuriant growth of a diverse assemblage of seaweeds on Saurashtra coast, is found to have abundant quantities of seaweeds being drifted and washed ashore every year. Studies conducted for quantifying the stranded seaweeds from May 2004 to April 2005 showed an average biomass value of 3.10 kg fresh wt/m$^2$/month with maximum being 6.60 kg fresh wt/m$^2$ in April. The stranded weeds constituted a total of 62 species during the entire study period. Of this, Rhodophyta ranked high with 26 species followed by Chlorophyta with 22 species and Phaeophyta with 14 species. The stranded seaweeds that were washed ashore provide valuable floristic information about the intertidal and near shore sub-tidal algae of the respective regions. Although natural senescence of seaweeds is one of the major factors, strong currents primarily forced by tides, also contribute to the uprooting and subsequent drifting of seaweeds on to the beach. This ultimately causes changes in floristic features of the existing algal beds.

## 1. Introduction

About 8 million tons wet seaweeds are harvested annually worldwide and stranded seaweeds on the beach constitute a considerable part of it (McHugh 2003). The stranded seaweeds on the beach are harvested and utilized for a variety of purposes such as feed, fertilizer and as a source of raw material for industrial production of phytochemicals of commercial importance (Kirkman and Kendrick 1997). In Australia, harvesting of kelp drifts from beaches is a major activity and provides a sizable income for island communities. However, for an ordinary person these are huge piles of decaying plant material washed ashore above the high tide mark of the beach. It has also been earlier reported that the phycocolloid content of the drift seaweeds is comparable with that of those obtained from freshly harvested biomass (Krishnamurthy 1967). Further, the beach fauna such as *Ligia pallasii*, *Traskorchestia traskiana* and *Megalorchestia californiana* have also been found to prefer stranded seaweeds as their feed rather than fresh ones (Pennings *et al* 2000). The stranded seaweeds at the surf zone also provide a niche environment for juvenile fishes and wrack-inhabiting organisms (Lenanton *et al* 1982). The seabirds are often seen feeding on beach-wrack. Accumulations of beach cast wreck are of immense ecological significance and contribute enormous quantities of organic matter which partly enters the trophic food chain and the remainder into the detrital pool either as particulate or dissolved organic matter in the ecosystem (Mitchell and Hunter 1970; Dooley 1972; Lenanton *et al* 1982; Robertson and Lenanton 1984; Safran and Omori 1990; Blanche 1992; Kirkman and Kendrick 1997).

**Keywords.** Abiotic factor; biomass; Port Okha; seasonal variation; stranded seaweeds.

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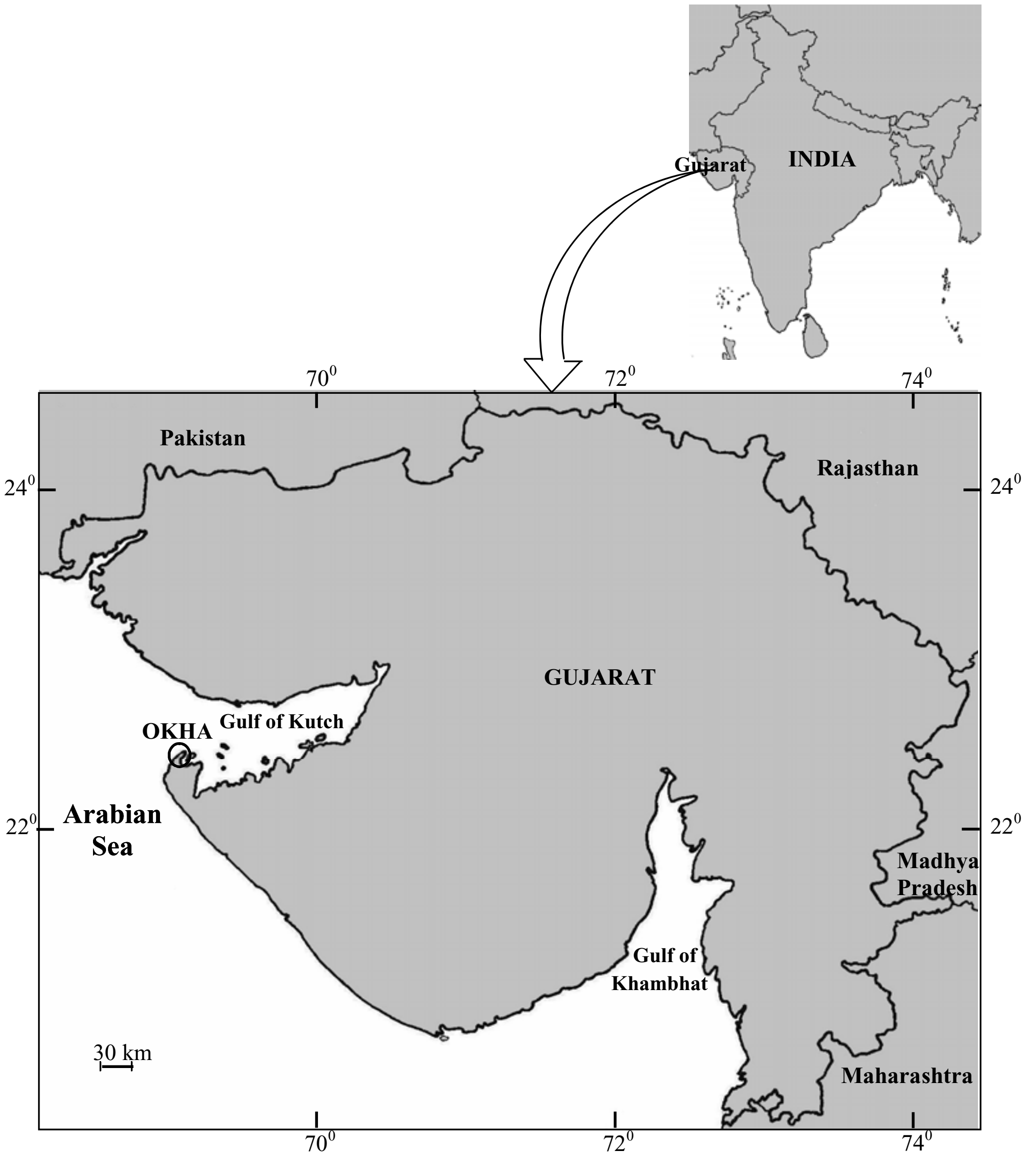


Figure 1. Map of India showing the study site of Port Okha.

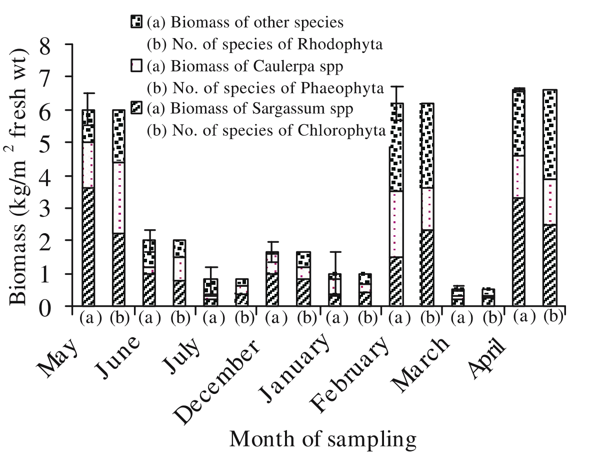


Figure 2. Biomass, species composition and dominant species of stranded seaweeds along Port Okha coast from May 2004 to April 2005.

Drifting of seaweeds has been reported from the Atlantic, Pacific and Indian Oceans and the Red Sea (Hirata *et al* 2003). In India, earlier studies have attempted to estimate drift seaweeds from selected parts of the Indian coasts (Mitra 1946; Krishnamurthy 1967). However, these studies are confined to estimate the most dominant species in the drift for a limited period. Initial efforts to estimate seaweed resources of the Indian coast were based on the weed washed ashore. Mantri and Chaugule (2005) reported ethanophycological use of drift seaweeds from the Maharashtra coast. In this paper, we report results of the systematic study undertaken to assess seasonal variation in biomass and species composition of stranded seaweeds together with causative factors that resulted in the drifting of seaweeds from May 2004 to April 2005 along the Port Okha coast.

## 2. Materials and methods

### 2.1 *Study site*

Port Okha (lat. 22°28′N and long. 69°05′E), situated at the mouth of "Gulf of Kutch" on the north-westernmost part of Saurashtra of Gujarat (figure 1) is one of the important places of interest for algal growth in the country (Mairh *et al* 1998). Physicochemical properties of seawater at Port Okha are as follows: temperature ranged from 21.5 to 30°C, salinity from 35.46 to 37.32 PSU, D.O. from 5.3 to 6.7 ppm, turbidity from 0 to 200 ppm, phosphate phosphorus from 0.1 to 1.05 $\mu$g atom/l, nitrate nitrogen from 2.0 to 11.5 $\mu$g atom/l (Chauhan 1965). This coast being at the mouth of "Gulf of Kutch" experiences strong water currents round the year as compared to other parts of the country. The coast is characterized by rocks made up of tertiary formations alternating with patches of sand deposits making the area more hospitable for the growth of all types of seaweed throughout the year (Børgesen 1934). Exposure of 0.7–0.9 km width of intertidal zone for 3–4 hours with tidal amplitude of 4–5 m creates a unique habitat for luxuriant growth of diverse seaweeds (Misra 1960).

### 2.2 *Sampling*

Sampling was done from the uppermost littoral zone at monthly intervals from May 2004 to April 2005 over 500 m coastal stretch at Port Okha. During the months of August–November there was no drift available and hence no data collected. This season is generally considered as a cryptic or pre-regeneration stage for seaweed growth for this location (Chauhan 1965; Ohno and Mairh 1982). During sampling, the shore-washed seaweeds were collected by placing 5 random quadrates of 0.25 $m^2$. The seaweeds which over-passed the edge of the quadrates were snapped with the help of a knife. The seaweeds thus harvested were separated species-wise, brought to the laboratory, washed and weighed for determining biomass. The data on species composition, abundance and biomass of stranded seaweeds for the entire study period are shown in the respective tables and figures.

## 3. Results

During the study period, stranded seaweeds constituted a total of 62 species (table 1). The diversity of the species in stranded seaweeds showed a declining trend from the month of June onwards. Although biomass values of stranded seaweeds varied with the month, the highest biomass values recorded for the months of February, April and May ranged between 6.0 and 6.6 kg fresh wt/$m^2$. The lowest biomass being 0.55 kg fresh wt/$m^2$ collected in March (figure 2). The total biomass of the stranded seaweeds during the entire study period (8 months) was 24.82 kg fresh wt/$m^2$ with the average being 3.1 kg fresh wt/$m^2$. Indeed, a major part of the stranded seaweed is represented by species of Rhodophyceae with 26, followed by Chlorophyceae with 22, and Phaeophyceae with 14. The seaweeds collected in December 2004 and February 2005 contained maximum diversity with as many as 29 species, and a minimum of 12 was in July 2004. However, *Sargassum* (Phaeophyceae) and *Caulerpa* (Chlorophyceae) are the two conspicuous partners that formed the major part of beach-stranded seaweeds throughout the study period (figure 2).

## 4. Discussion

The biomass as well as species composition of stranded seaweeds largely depend upon season, population structure and several other ecological factors (Krishnamurthy 1967). Further, the vegetation cover, age and height of individual plants, morphology and structure of thallus also contribute to the drifting of seaweeds (Norton *et al* 1982). The biomass of seaweed drifted to the coast can be correlated with the abiotic factors that prevailed before or during the collection period (McQuaid 1985). When the seaweeds get detached from its natural habitat due to any reason, it could be washed ashore forming the stranded seaweeds at the beach.

It is evident from data that the maximum drift of seaweeds occurred during February, April and May which is generally considered as a peak growth period for many types of seaweed on the Okha coast. Seaweeds as compared to other marine plants are short-lived with successive growth periods and more than two growth peaks during their life span when the season is conducive. The lowest values obtained during March could be attributable to an intermittent period in which some seaweed populations rejuvenate and recover from wholesome detachment. The seasonal variation in species composition of stranded seaweeds in the present study is correlated with species succession in the natural seaweed habitat of Port Okha coast (Murthy *et al* 1978). The seaweed growth season on Okha coast is spread over to seven months beginning from November to May. During this period, the coast witnesses extensive growth and succession of different types of seaweed. The monsoon period (June–September) is a lean period

Table 1. *Species abundance of drift seaweeds along the Port Okha coast from May 2004 to April 2005.*

| | Months | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Species | May | June | July | December | January | February | March | April |
| **Chlorophyta** | | | | | | | | |
| *Acrosiphonia orientalis* (J. Agardh) P. Silva, *com. nov.* | – | +++ | – | – | – | – | – | – |
| *Boodlea composita* (Harvey) Brand | – | – | – | ++ | – | + | – | – |
| *Bryopsis plumosa* (Hudson) C. Agardh | +++ | + | + | – | – | – | – | – |
| *Caulerpa racemosa* (Forsskål) J. Agardh var. *macrophysa* (Sonder ex Kützing) W. R. Taylor | +++ | – | – | ++ | ++ | + | ++ | ++ |
| *C. scalpelliformis* (R. Brown ex Turner) C. Agardh | – | – | – | – | +++ | ++ | – | – |
| *C. sertularioides* (S. Gmelin) Howe | – | – | – | ++ | +++ | ++ | + | ++ |
| *C. taxifolia* (Vahl) C. Agardh | ++ | ++ | – | – | + | +++ | + | + |
| *C. veravalensis* Thivy & Chauhan | – | – | – | +++ | ++ | – | – | – |
| *C. verticillata* J. Agardh | + | + | + | ++ | – | – | – | – |
| *Chaetomorpha crassa* (C. Agardh) Kutzing | – | – | – | – | – | ++ | + | + |
| *C. spiralis* Okamura | + | – | – | + | ++ | + | + | + |
| *Codium elongatum* Børgesen | ++ | – | – | – | – | – | – | – |
| *Dictyospheria cavernosa* (Forsskål) Børgesen | + | – | – | – | – | – | – | – |
| *Enteromorpha compressa* (Linn) Nees | – | – | – | ++ | – | + | – | + |
| *E. intestinalis* (Linn) Nees | – | – | – | + | + | – | – | ++ |
| *Halimeda tuna* (Ellis & Solander) Lamouroux | ++ | ++ | – | + | ++ | – | – | – |
| *Struvea anastomosans* (Harvey) Piccone & Grunow ex Piccone | – | – | – | + | – | ++ | – | – |
| *Ulva fasciata* Delile | – | – | ++ | ++ | – | ++ | – | + |
| *U. lactuca* Linnaeus | +++ | – | + | ++ | – | ++ | – | + |
| *Udotea flabellum* (Eliss & Solander) | – | – | ++ | – | – | – | – | – |
| *U. indica* A. Gepp & E. Gepp | – | – | + | + | – | – | – | – |
| *Valoniopsis pachynema* (G. Martens) Børgesen | ++ | ++ | – | + | – | – | – | – |
| **Phaeophyta** | | | | | | | | |
| *Colpomenia sinuosa* (Merens ex Rotyh) Derbes & Solier | ++ | – | – | ++ | – | – | – | ++ |
| *Cystoseira indica* (Thivy & Doshi) Mairh | ++ | ++ | – | – | + | – | – | ++ |
| *C. trinodis* (Forsskal) C. Agardh | + | – | – | – | – | – | – | + |
| *Dictyopteris australis* (Sonder) Askenasy | – | – | – | – | – | +++ | – | – |
| *Dictyota dichotoma* (Hudson) Lamouroux | ++ | – | – | – | – | ++ | – | – |
| *Dilophus* sp. J. G. Agardh | + | – | – | + | – | - | – | – |
| *Iyengarii stellata* (Børgesen) Børgesen | – | – | – | +++ | ++ | ++ | – | – |
| *Lobophora variegata* (Lamouroux) Womersley ex Oliveria | – | + | – | – | – | – | – | – |
| *Padina tetrastromatica* Hauck | ++ | ++ | ++ | ++ | – | + | – | – |
| *Sargassum swartzii* C. Agardh | +++ | + | – | ++ | + | – | ++ | +++ |
| *S. tenerrimum* J. Agardh | ++ | +++ | ++ | + | ++ | ++ | + | +++ |
| *Spatoglossum asperum* J. Agardh | + | – | + | ++ | – | ++ | – | – |
| *S. variabile* Figari & De Notaris | – | + | – | – | – | – | – | – |
| *Stoechospermum marginatum* (C. Agardh) J. Agardh | ++ | – | – | – | – | – | – | – |

Table 1. *(Continued)*

| Species | May | June | July | December | January | February | March | April |
|---|---|---|---|---|---|---|---|---|
| | Months | | | | | | | |
| **Rhodophyta** | | | | | | | | |
| *Agardhiella subulata* (C. Agardh) Kraft & Wynne | + | – | – | + | – | – | – | – |
| *Amphiroa anceps* (Lamarck) Decaisne | + | ++ | ++ | + | + | – | – | – |
| *Asparagopsis taxiformis* (Delile) Trevisan | – | – | – | – | – | – | – | ++ |
| *Botryocladia botryoides* J. Agardh | ++ | + | + | – | – | – | – | – |
| *Ceramium rubrum* Auctorum | – | + | – | + | – | – | – | + |
| *Champia globulifera* Børgesen | – | – | – | – | – | ++ | – | – |
| *Chondria dasyphilla* (Woodward) J. Agardh | – | – | – | – | – | + | – | ++ |
| *Coelarthrum muelleri* (Sonder) Børgesen | – | – | – | – | – | ++ | + | + |
| *Corynomorpha prismatica* (J. Agardh) J. Agardh | + | ++ | – | – | – | – | – | – |
| *Cryptonemia undulata* Sonder | – | – | – | – | – | – | – | + |
| *Gracilaria verrucosa* (Hudson) Papenfuss | – | – | – | + | + | – | – | + |
| *Grateloupia indica* Børgesen | – | – | – | – | – | + | ++ | + |
| *Griffithsia rhizophora* Frunow ex Weber – van Bosse | – | – | – | – | – | +++ | ++ | – |
| *Halymenia venusta* Børgesen | ++ | – | – | + | – | ++ | +++ | ++ |
| *Heterosiphonia muelleri* (Sonder) De Toni | – | – | – | +++ | +++ | – | – | – |
| *Hypnea musciformis* (Wulfen) Lamouroux | – | – | – | – | + | +++ | – | +++ |
| *Hypoglossum heterocystideum* (J. Agardh) J. Agardh | – | – | – | – | – | – | +++ | – |
| *Jania rubens* (Linnaeus) Lamouroux | – | – | – | – | – | – | – | + |
| *Leveillea jungermannioides* (Hearing & G. Martens) Harvey | – | – | – | + | – | – | + | – |
| *Lophocladia lallemandi* (Montagne) Schmitz | – | – | – | – | – | + | – | – |
| *Polysiphonia platycarpa* Børgesen | – | – | – | – | + | + | – | – |
| *Predaea feldmanni* Børgesen | – | – | – | – | – | | | ++ |
| *Sarconema scinaioides* Børgesen | + | – | – | ++ | ++ | + | – | – |
| *Scinaia hatei* J. Agardh | ++ | – | – | – | – | ++ | – | – |
| *Scinaia monoliformis* J. Agardh | – | – | – | – | – | +++ | – | – |
| *Solieria robusta* (Greville) Kylin | – | – | – | – | – | – | +++ | – |

+++ dominant; ++ average; + meager and – absent.

Table 2. *Wind velocity (24 hours) at Port Okha during the study period.*

| Date and time of sampling | Wind direction | Wind velocity* | | | | | |
|---|---|---|---|---|---|---|---|
| | | 4 h | 8 h | 12 h | 16 h | 20 h | 24 h |
| May 2004 | SW | 1 | 1 | 1 | 1 | 1 | 1 |
| June 2004 | SW | 3 | 3 | 3 | 3 | 3 | 3 |
| July 2004 | SW | 1 | 1 | 1 | 1 | 1 | 1 |
| December 2005 | NE | 2 | 2 | 2 | 3 | 3 | 2 |
| January 2005 | SE | 3 | 2 | 2 | 2 | 2 | 3 |
| February 2005 | NE | 1 | 1 | 1 | 1 | 1 | 1 |
| March 2005 | SE | 1 | 1 | 1 | 1 | 1 | 1 |
| April 2005 | SW | 2 | 2 | 1 | 1 | 2 | 2 |

*1 = 18.52 − 27.78 km/h, 2 = 27.78 − 37.04 km/h, 3 = 37.04 − 46.30 km/h
(Source: Coast Guard Station, Okha Port, Okha).

supporting scanty growth of a few species confined to supra littoral zone.

Therefore, the extensive drifting of seaweeds always occurs during the tail end of the seaweed growth period. This is the period many seaweeds attain senescence and any wave action with moderate force together with changes in seawater temperature, uproot the plants causing floating and stranding to the beach. The observed wind speed at Port Okha during this period varied from 18.5 to 46.3 km/hour (table 2; A Das, personal communication 2007) and water currents at Port Okha range from 1.5 to 2 m/s (Capt. R K Raman, personal communication 2007). The observed winds are unable to generate strong enough local currents, but there are two other processes that are important. The strongest currents around Port Okha are associated with the tides, which force currents as strong as 1–2 m/s (Unnikrishnan and Luick 2003), comparable to the currents observed in the region. An additional contribution comes from the large-scale wind-forced circulation, which is associated with monthly-mean current speeds of about 0.5 m/s during May (Mariano *et al* 1995; Shankar *et al* 2002). The resultant current speeds in excess of 2 m/s can cause uprooting of the seaweeds. Water velocities causing uprooting of seaweeds in seaweed zone have also been reported by Jones and Demetropoulos (1968).

Since the study site at Port Okha is a protected and sheltered bay, the seaweed biomass from nearby places and upstream areas gets concentrated in this region and piles-up on the beach as a result of wave action. The size of the drift or stranded seaweed is indicative of the existence of algal beds in coastal waters. The greater the drift the larger the algal community in existance. There is no any definite pattern in the species composition of stranded seaweed. However, the clear-cut dominance of members of Chlorophyceae could be attributed to the simple paranchymatous nature of the fronds. Moreover, the entire algal thallus is exposed to motion, unlike a land plant in which the anchoring roots are beneath the soil and out of the wind. This kind of wave action may hardly be tolerated by the Chlorophycean members with soft thallus. However, the Rhodophycean members, which tend to drift, are mostly of cartilaginous and fragile causing breaking of thallus. *Sargassum* and *Caulerpa* are the two taxa that contributed to maximum stranded seaweed biomass. This could be due to the branched, anastomizing habit of fronds, resulting into extensive spread in the intertidal area as compared to other seaweed species. Krishnamurthy (1967) found that the seaweeds washed ashore during November and December were very less but abruptly increased in January.

The *Sargassum* was the major constituent in the drift while only a small amount (less than 1%) was contributed by the other alga. In the present study, the seaweeds stranded ashore were negligible during December and January but suddenly increased by a factor of 6 times in February. The life history and phenology of *Sargassum* species and its recruitment dynamics have extensively been investigated (Chauhan and Krishnamurthy 1967a, 1967b; Raju and Venugopal 1971; Chauhan 1972; Chauhan and Mairh 1978; Kendrick 1994; Kendrick and Walker 1995). *Sargassum* species are canopy-forming algae up to 120 cm tall; and commonly grow in semi-exposed habitats from the intertidal to subtidal reefs (up to 30 m depths) in tropical and temperate regions (Chauhan 1972; Kirkman and Kendrick 1997). The *Sargassum* forest plays an important role in marine ecosystem. The commercially important fish spawn, abalone and turban shells are usually found to inhabit the *Sargassum* forest (Komatsu *et al* 2007). The drifted and floating fronds of *Sargassum* provide the habitat for juvenile fishes (Lenanton *et al* 1982) and provide a base for the food chain for pelagic seabirds. Most of the species of *Sargassum* occurring on the Gujarat coast complete their life cycle in the months of November–December and May–June and later get detached from their natural habitat due to senescence.

*Caulerpa* Lamouroux is a highly polymorphic genus belonging to the family Caulerpaceae inhabiting in warm waters (Silva 2002). The monographic account on the *Caulerpa* species in India has been described by Duraiswamy (1989, 1990a and b). The *Caulerpa* species are normally 0.75 mm (*Caulerpa verticillata*) to 185 mm (*Caulerpa taxifolia*) tall and grow as creepers on rocks (e.g. *C. microphysa*), in pools (e.g. *C. recemosa* var. *occidentalis*), on sandy patches of middle and lower intertidal regions (e.g. *C. sertularioides*), on submerged subtidal rocks (e.g. *C. taxifolia*) and on muddy upper littoral zones (e.g. *C. verticillata*) (Mantri *et al* 2004). Most intertidal plants experience desiccation and water abrasion and many of the seaweeds uprooted by wave abrasion are cast on nearby shores. Moreover, the forms present in the drift are not hydro dynamically strong and transmit all wave exerted pressure on their holdfast leading to rapid dislodgement. On the contrary, some seaweed species like *Gelidiella* and *Gelidiopsis* are relatively small in size but have a very strong anchoring system that enables them to withstand wave action and prevent them from dislodgement and subsequent drifting even during rough sea conditions.

The stranded seaweeds that are washed ashore provide valuable floristic information about the respective intertidal and near shore sub-tidal regions. The stranding of seaweeds along the coastline is not only due to the function of natural senescence and death but also due to uprooting by the heavy winds and water currents often occurring in the coastal regions. This ultimately causes changes in floristic features of the existing algal beds.

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